

## **Integrating Engineering throughout K-12 Classrooms: A Working Model for Involvement of Teachers**

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### **Abstract**

Four Massachusetts universities are working together to provide engineering design content and support for teachers from across the state. The focus of this NSF funded project is to provide professional development opportunities to strengthen the background of teachers, and to guide them with implementation ideas and support as they bring engineering into to their classes. The project is currently in the first year of a five-year program that establishes mentor teachers who then assist in the dissemination to other teachers from their grade levels. The initial set of teachers is high school educators. In subsequent years middle school, late elementary, and early elementary teachers will have the same professional development and mentoring opportunities.

### **Introduction**

In response to the educational reform act of 1993<sup>1</sup>, Massachusetts implemented statewide curriculum frameworks in 1994. The state education reform included a mandated review of the content standards used in the curriculum frameworks after five years of implementation. Review of the initially implemented sciences standards, along with knowledge of the newly framed vision for technological literacy presented in *Technically Speaking, Why all American Should be Technologically Literate*<sup>2</sup>, and the International Technology Education Association (ITEA) standards<sup>3</sup>, lead to the newest Science and Technology/Engineering Curriculum Frameworks<sup>4</sup>. Also as part of the education reform act, the state of Massachusetts has implemented a high stakes testing system throughout its pre-college educational system to test student knowledge in various areas of the state set curriculum frameworks. These tests are known as the Massachusetts Comprehensive Assessment System (MCAS.) The science and technology/engineering exam is currently given to students in grades five and eight, and a tenth grade exam in technology/engineering is presently under development. At the fifth and eighth grade level, technology/engineering questions make up 25% of the exam - yet technology education is typically taught as an elective course in which many students do not participate.

To help in addressing this issue, a group of four higher education institutions from across Massachusetts have partnered together through a grant from the National Science Foundation in a multi-year program entitled Pre-college Engineering for Teachers (PCET)<sup>5</sup>. The aim of this program is to allow math, science, and technology teachers to attend a professional development workshop in teams where they learn about the engineering design process for implementation

into their classrooms. During the academic year, the teachers are supported by their local university as they implement the concepts and complete design projects with students in at least one of their classes. In addition, they also must participate in further dissemination of the content and classroom applications to additional teachers from their local area through satellite workshops.

The partnering universities work with the PI at Tufts University as well as professors at Worcester Polytechnic Institute, the University of Massachusetts at Lowell, and the University of Massachusetts at Amherst. These institutions are located throughout Massachusetts, thus providing a greater reach than a single institution would have. In this project, each of the universities supports a set of teachers who represent multiple schools located near that university. A graduate student and faculty member from each university act as local contacts and resources for those teachers.

### **Content for Teachers**

During the summer of 2003, 22 high school teachers from nine high schools across the state of Massachusetts began their commitment to the PCET program by participating in a two-week professional development workshop held at Tufts University. The teachers from each high school comprised a diversified team of math, science, and technology education instructors. Recruitment of the teams in the preceding year encouraged this diversification in order to allow engineering education to be introduced in a wide range of subject areas and for the teachers to have colleagues at their own school supporting them as they implement the new ideas.

The workshop was a learning opportunity that included a series of speakers, activities, group discussions, and field trips, all designed to provide the teachers with a better understanding of the engineering design process and ways to implement that process into their classrooms. The overall theme of the workshop was engineering design, and within that, there were two major themes. Water treatment and assistive technology were chosen for these because they each can be applied to a wide variety of subject areas. Assistive technology applies to a "range of devices, services, strategies, and practices that are conceived and applied to ameliorate the problems faced by individuals who have disabilities<sup>6</sup>." Examples of assistive technologies include wheelchairs, hearing aids, large print text, and accessibility requirements for public buildings. Design of water treatment devices requires chemistry and biology, while assistive technology devices are generally mechanical and/or electrical in nature and require some knowledge of mathematics and physics to construct. It was the intent that each teacher, if she chose to, could use one or both of the larger scale projects in her classroom to fulfill the PCET project requirement for the coming school year.

A large percentage of the time during the workshop was allocated to putting the design process into practice through a series of small and larger scale activities and group discussions that the teachers could then take to their classrooms. All activities emphasized the importance of teamwork. At the beginning of the program, the teachers were introduced to the engineering design process as it is laid out in the Massachusetts Curriculum Frameworks. The process

includes the following steps: 1) Identify the problem, 2) Research the problem, 3) Develop possible solutions, 4) Select a solution, 5) Construct a prototype, 6) Test/Evaluate the Solution, 7) Share the Solution, 8) Redesign. This process was continually referred to throughout the workshop. The following table presents a ‘general’ day during the workshop. It shows the kind of activities and information that the teachers were exposed to and the time allotted for each.

Table 1 Basic Workshop Schedule

	Type of Activity	
am	Engineering topics lecture	1 hour
	Small project work	1 hour
	Group discussion	30-45 minutes
	‘Big Picture Lectures’	1 hour
pm	Lunch	1 hour
	Teamwork on projects	3-4 hours
		total = 8 hours

The small projects had several purposes. These included getting the teachers working in teams, providing ideas they can implement in their classes, and showing how the engineering design process plays out as a process. When possible, the small project work was tied to the engineering topic lecture. Many of the small projects done during the workshop are listed in Table 2.

Table 2 Examples of Small Projects

Project	Activity Description	Desired Outcome/Goal
Tower	Build the tallest index card tower in limited time while having to compensate for constraints introduced halfway through the construction period.	Demonstrate that in real engineering problems constraints can be introduced at any time.
Faucet	Describe how a faucet works while looking at the assembled product. Then take apart the faucets and examine the mechanisms inside.	Raise awareness and curiosity about the engineering of everyday objects.
ProDesktop/CAD	Learn the basics of Computer Aided Design (CAD) through the design of several shapes.	Earning a certification that entitles them to copies of the software for use in the classroom.
Straw holder	Design a straw holder for a man with limited use of his upper body. Take the provided descriptions of the ideal straw holder and use those specifications for prototype designs.	Show that sometimes not all specifications can be fully met.
Concrete blocks	Teachers mixed and poured their own blocks of concrete from a new type of aggregate made from recycled plastic.	Introduce potential uses for this new type of concrete.

The group discussion topics supported and expanded the teachers' knowledge, and included an explanation of engineering, the design process, and how engineering design fits into the MA curriculum frameworks.

The teachers completed one larger scale project during each of the two weeks of the workshop. These projects required an in depth use of the design process and allowed them to integrate their subject area (mathematics, science, or technology education) as they wished. Approximately three to four hours a day for three days was dedicated to each larger scale project. The first project was a water treatment project in which teachers worked in teams of five to six teachers to build their own water filters using fairly crude materials. The filtered water was tested, and teams competed to produce the "cleanest" filtered water. The second project focused on assistive technology, and the groups were given free range to design any type of assistive technology device they chose. For both of these projects, the teachers were required to go through each step of the design process and present their solutions to the rest of the teams at the conclusion of the project.

Engineering topic lectures were given by 12 speakers from industry, academia, and research. They spoke to the teachers about different fields of engineering, focusing on their own area of expertise. Some of the speakers' topics coincided with the projects and activities to give the teachers a better understanding of the subject matter. The big picture presentations showed many aspects of engineering on large scale projects. These presentations included the Big Dig (a massive undertaking in Boston in which a large section of the interstate is being moved underground), computer engineering, plastics engineering, human factors engineering, traffic engineering, and telecommunications engineering. The teachers also went on field trips related to the project work. Places visited were the Cambridge Waterworks, the Perkins School for the Blind, and the Boston Museum of Science.

The final component of the workshop was for the teachers to develop and submit descriptions of the design project(s) they intended to do with their students during the following year. In the descriptions, they outlined the courses in which they would use the projects, the engineering concepts the project would encompass, the timeline of the project, requirements of the students, materials involved, and how the graduate student from their local university could be helpful during the year. The teachers could use one of the projects done during the workshop, but were also encouraged to use their own ideas.

## **Implementation**

As of January, not every teacher had completed their project, although it is required that all projects be finished by the end of the 2003-2004 school year. Because design projects can be material intensive, each teacher was allotted \$250 to spend on their project(s), giving them an incentive to try a new approach to teaching in their field. Seven of the 22 teachers planned to use one of the projects from the workshop, the most popular being a variation on the water filter project. Some of the other projects teachers planned to do with students during the year are

described below. The wide variety of projects below shows the ease with which engineering can be integrated into any math, science, and technology classroom.

Several projects are presently in progress, including one done by a ninth grade general science teacher in the field of assistive technologies engineering. In this project, three subsets of students were given the challenge to “build something useful for the special education classroom using the engineering design process.” The students first sat in on several classes taught in special education classrooms. After discussing the students’ needs with the special education teachers and paraprofessionals, each team of four to five students came up with possible solutions. Ideas were evaluated and selected using a design matrix, and construction options were discussed. The students were required to submit scaled drawings to the teacher, which were then discussed at length for feasibility. The final designs decided upon are a communication board that is age appropriate for several higher-level special education students, a cube with push buttons on all sides that make noises when pushed, and a memory game. All three groups are presently in the construction phase of this project.

Another project has several groups of biology students designing a habitat and testing apparatus for hamsters. These students are “contracting” the actual building of the habitat and apparatus out to a group of construction technology students who are at the same school, but in a different class. In this case, the communication portion of the engineering design process is emphasized by the biology teacher, as the two groups of students are only allowed to communicate in written form.

Other projects include a physics teacher who is modifying his existing end of the year project building wind chimes to include an engineering design component. Another example is that of a mathematics teacher who noticed congested foot traffic in a section of her school that was under construction. She intends to examine traffic flow patterns, and have her students design solutions to this problem. A technology teacher is having his students design both concrete mixes and the forms they will be poured in, and will be testing these to determine the strongest mix.

Beyond the individual classroom, another goal of the PCET program is to set up a district and state-wide network of teachers who have the background to integrate engineering into their classrooms in the next year. To assist with this, the teachers who participate in each summer workshop are required to hold a similar workshop the following summer. The satellite workshops are held at each partnering university which recruits teams of teachers from the same grade levels in nearby school districts. Through periodic meetings, these new teachers will be mentored by the more experienced teachers, and will hopefully be able to seamlessly integrate engineering into their classrooms. Eventually, all projects done by the teachers will be entered into an on-line database and will be available for all to use.

## **Impact**

Teachers from the summer 2003 workshop were exposed to a wide variety of engineering

disciplines. It was found from the survey completed by the teachers that over 80% of the teachers felt that their knowledge of the range of engineering disciplines, the engineering design process, and the MA technology/engineering curriculum frameworks increased as a result of the two-week workshop. They were glad to have had the opportunity to network with teachers from other school districts, and felt that the activities and projects presented during the program would be useful in the classroom. The teachers felt overall that the workshop time provided them with a strong foundation of knowledge, practice, and valuable resources necessary to introduce the engineering design process to their students.

Because the high school portion of the PCET project is still in its first year, it is difficult to fully assess its impact. However, preliminary data gathered by the project coordinator, graduate students, and teachers indicate that many of the goals of PCET are being met. Through quizzes and examinations, it is clear that students are learning the engineering design process. Informal interviews indicate that student views on engineering are changing for the better as they are working on their projects. Several students have also commented on how much they enjoy the non-traditional approach to the subject that they are learning.

While a preliminary teacher network has been set up among the participants of the summer 2003 program, the final support network for them will not be fully established until the completion of the summer satellite workshops. Communication between all of these teachers is one of the most crucial parts of the PCET program. Not only does it give teachers the opportunity to meet other teachers in their disciplines, but also allows them to exchange ideas, resources, and information concerning their engineering based projects. This network also provides teachers with the pilot projects done previously by other teachers who found them to be successful with their classes.

The middle school summer workshop and high school satellite workshops are due to begin in the summer of 2004, each accommodating approximately 24 teachers. Although recruitment is still in progress until the end of January 2004, there are currently 11 teachers signed up for the 2004 summer high school satellite programs, and 26 middle school teachers have applied to the middle school workshop. All five workshops will be evaluated by the teachers in order to help improve content for the middle school satellites and the upper and lower elementary level workshops.

## **Conclusion**

To date, the PCET program has been judged to be worthwhile and rewarding by all of its participants, as evidenced by the feedback from the teachers and enthusiasm of the students toward their engineering design projects. By the summer of 2004, after the completion of one year of high school student projects, the high school satellite development workshops, and the initial middle school workshop, more definitive confirmation as to whether or not the program has been successful in its pilot year will be available.

The program participants and coordinator are aiming to recruit the maximum number of teachers that can be accommodated by the grant for the 2004 summer workshops. Ideally, this would mean that a total of 96 high school teachers would attend the four summer high school satellite

programs held at the partnering universities (24 teachers per university.) With this achievement in mind, 118 teachers would have been trained directly through the PCET program to introduce the engineering design process into their classrooms. With an average class size of 20, this means that potentially 2,800 high school students in Massachusetts could be exposed to the engineering design process during the first two years of the program. These numbers will increase as the program continues to endure and grow, expanding to the middle and elementary school level. This growth meets the project goal of helping teachers and schools increase the number of students who are better equipped for the technology/engineering component of the MCAS exam. In addition, these students will be exposed to new career opportunities and further development of problem solving skills that can be applied to all areas of their lives.

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Bonniejean Boettcher is a first year graduate student of Mechanical Engineering at Worcester Polytechnic Institute. Her thesis work deals with gait analysis and her main interests lie in design of assistive technology. She received her B.S. in Biomedical Engineering from Worcester Polytechnic Institute in 2002.

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Bree Carlson has been a graduate student at the University of Massachusetts at Amherst since 2001 and will be receiving her master's degree in Environmental Engineering in 2005. Her two main areas of interest include science/engineering outreach and inexpensive drinking water treatment alternatives for developing nations. She received a B.A. in Astronomy from Smith College in 2001.

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Martha Cyr is the director of K-12 outreach an adjunct professor with the Mechanical Engineering Department at Worcester Polytechnic Institute in Worcester, Massachusetts. Her main area of interest is effective engineering education for all ages. Dr. Cyr received her B.S. in Mechanical Engineering from the University of New Hampshire in 1982, and her M.S. and Ph. D. in Mechanical Engineering from Worcester Polytechnic Institute in 1987 and 1997.